

THERMAL WAVE EVALUATION OF KAPTON^{*}-LAMINATED COPPER DIFFUSION BONDS

J. Jaarinen^{**}, L.D. Favro, P.K. Kuo, and R.L. Thomas
Department of Physics
Wayne State University
Detroit, MI 48202

and

C.M. Woods and G.L. Houston
Monsanto Research Corporation, Mound Facility
Miamisburg, Ohio 45342

INTRODUCTION

In this work we report the application of thermal waves to the nondestructive evaluation of multilayered samples. We have studied diffusion bonding of copper films laminated between Kapton films. We discuss the possibility of measuring the size and quality of the bonds. Delaminations elsewhere in the multilayered material have also been detected. The measurements include cases of artificial defects in the bonds and between the copper and Kapton films as well as cases of real defects. The measurement method used was the conventional infrared thermal wave imaging system. It is shown that the bonds can be analyzed and delaminations detected by thermal waves in these multilayered samples.

THEORETICAL BACKGROUND

Thermal wave detection of the quality of the contact between two layers of material is based on the changes in the thermal contact resistance of the boundary. Thermal contact resistance can be defined by a boundary condition for the temperature. The discontinuity of temperature at the boundary is proportional to the product of the heat flow through the boundary and the thermal contact resistance,

$$T_1 - T_2 = rH, \quad (1)$$

where T_1 and T_2 are the temperatures of the materials at the boundary, r is the thermal contact resistance and H the heat flux. If the contact is ideal, then r is equal to zero, which is equivalent to the usual boundary condition $T_1 = T_2$.

* Polyimide film, reg. U.S. Patent Office, E.I. du Pont Nemours and Co., Inc.

** Permanent address: Department of Physics, University of Helsinki, Siltavuorenpenger 20 D, 00170 Helsinki, Finland

The reflection coefficient, R , of the thermal wave at a boundary can be written using the thermal impedances of the materials and the thermal contact resistance.

$$R = (z_1 - z_2 + r)/(z_1 + z_2 + r). \quad (2)$$

The thermal wave impedance of a material is given by

$$z = (1+i) (1/2 \kappa c \rho \omega)^{1/2}, \quad (3)$$

where κ is the thermal conductivity, c is the specific heat, ρ is the mass density of the material, and ω is the angular frequency of the wave.

In the case of a delamination, the thermal contact between the layers is usually very weak. Thus, delaminations are associated with high thermal contact resistance. In the case of a totally delaminated boundary, the thermal contact resistance is very high and the reflection coefficient is very near +1, i.e. the wave is almost totally reflected. In a photothermal infrared measurement the wave is detected through its influence on the surface temperature which results from an interference between the generated and reflected thermal waves.

Thermal contact resistance is determined by the quality of the thermal contact at the boundary. However, usually one is not interested in the quality of the thermal contact but rather the strength of the adhesion between the layers. No simple answer can be given to the question as to whether any correlation exists between the strength of the bond and the quality of the thermal contact. If the layers are physically separated (a delamination), there is no mechanical contact or bond between the layers and also the thermal contact resistance of the boundary is high. However, if the layers are touching without any physical bond, the thermal contact can still be good. We shall later give an example of this kind of situation.

EXPERIMENTAL

In this work we have studied laminated samples consisting of alternating layers of Kapton, Pyralux, copper, and epoxy. A schematic picture of the structure is given in Fig. 1. Two different aspects were under investigation: the quality and size of the diffusion bonds between the copper films and delaminations between any layers in the structure. A likely location for delaminations was the region between the two welded joints underneath the thin copper film, because the lower layers of the structure must bend towards the surface in that area.

The samples were investigated using a conventional infrared thermal wave imaging system. The sample was placed on a stepping motor driven translational stage (resolution 6.35 microns). Thermal waves were generated at 5 Hz by a chopped Ar^+ -laser beam. The laser light was almost totally absorbed near the surface of the sample. Practically no transmission of the excitation light was detected through two layers of the orange-colored Kapton. The laser beam was focussed to about 0.2 mm diameter. The thermal wave at the surface of the sample was detected by a partially focussed pyroelectric infrared detector (a 25 mm Ge-lens was used with a Plessey PPL255 detector). The magnitude and phase of the signal were measured using a lock-in analyzer (PAR5301) and plotted using a recorder.

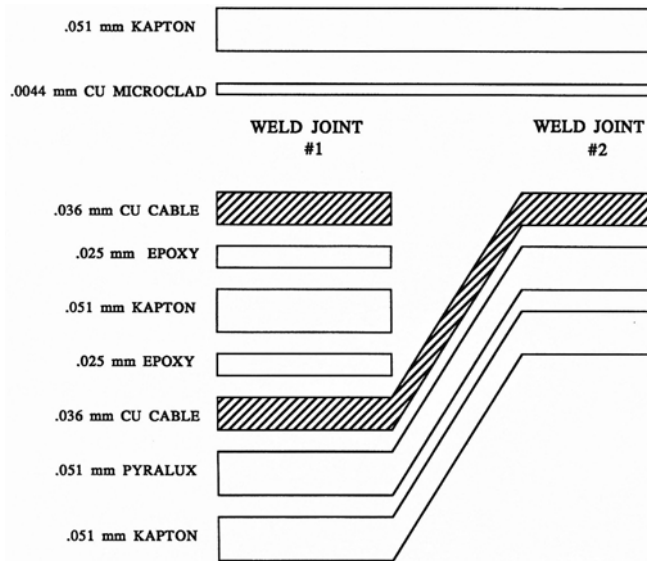


Fig. 1 Schematic diagram of the samples. Each sample included two diffusion bonds. The samples were line-scanned over the centers of both diffusion bonds and through the area between the bonds, where delamination between the copper and Pyralux film was expected.

All the samples were linescanned over the center of the diffusion bonds and the area between them. The scan speed was about 3 mm/min.

RESULTS

Let us first consider the diffusion bonds. Fig. 2 represents different scans over weldings. The left column indicates the magnitude signals and the right column the phase signals. In the case of these multi-layered samples the magnitude seems to reflect the structural differences better than does the phase. The thicker of the copper films acts as a heat sink, which can be seen as a common magnitude decrease in the areas, where the copper films are in contact. The typical magnitude signal for a good contact, in arbitrary units, is 12 ± 1 . The phase is also advanced for the same locations.

The two uppermost scans A and B are for samples without any diffusion bonds, i.e. the films are only laminated. However, the results indicate that the copper films are in good thermal contact in scan A. This is in agreement with electrical measurements carried out for similar samples by two of us (CMW AND CLH). The missing adhesion results easily in a delamination, which is the case shown in scan B. The thermal contact is fairly good on the sides of the possible contact area, but at the center the films are clearly separated by a gap. This particular case was confirmed by a visual inspection of the sample.

Scan C represents a normally welded joint. The diameter of the bonded area is about 1.5 mm, which is about half of the total possible diameter (compare with scan A). Around the joint there is some delamination, possibly due to the slight deformation resulting from the bonding process. Scans D and E represent normally bonded cases, but in situations for which the films were not cleaned prior to

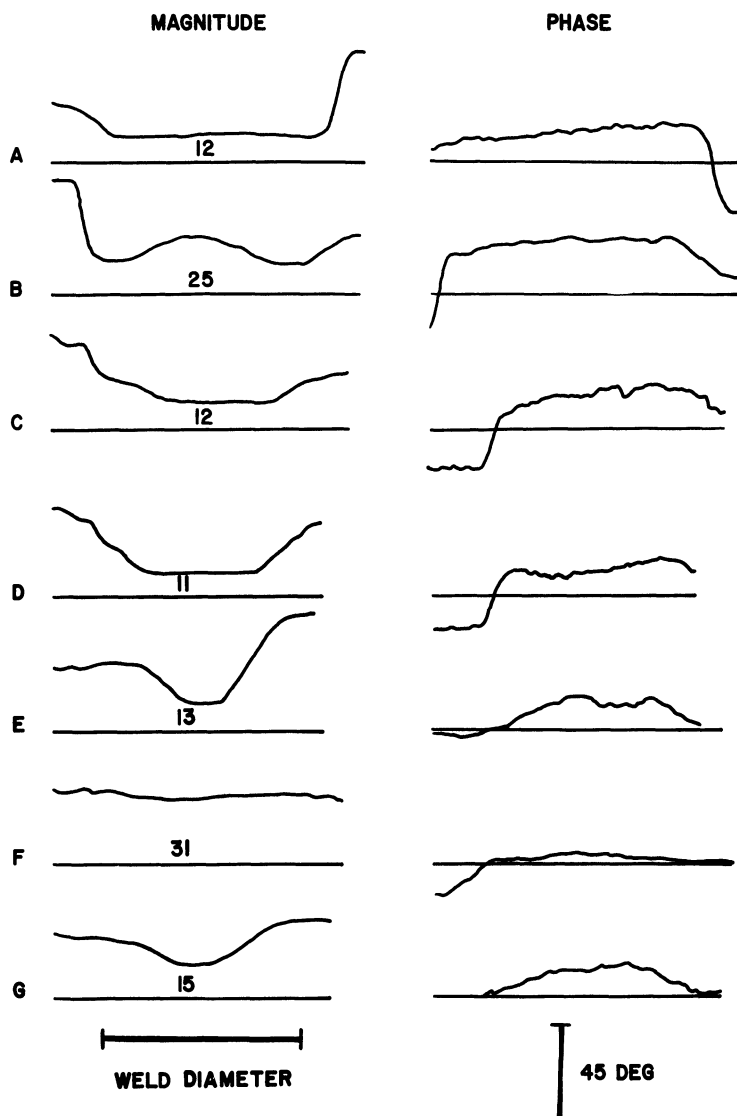


Fig. 2 The results of linescans over the diffusion bonds. Analyses of the results are given in the text.

lamination. This is expected to generate weak or defective bonds. The bond 1 (Fig. 1) shows a normal good weld. The diameter of the contact area is about the same as in the scan C and the overall behavior of the magnitude and phase are the same. The other bond has a flaw in it. The diameter of the contact area is only one third of that of a good weld. The delamination around the weld is also pronounced.

Samples used for scans F and G include artificial defects: a teflon film has been placed between the copper films to generate and simulate a delamination. For scan F the teflon covers the total contact area resulting in a constant magnitude over the area, and an increase in the phase lag. In scan G, the teflon films covers the

area to the right of the vertical line in the plots. The resulting weld is only to the right of the teflon film and is also weaker than a normal weld. The signal at the center of the weld is 15 instead of 12.

In order to study the delaminations in the area between the joints, several differently prepared samples were studied. A typical signal for a normally processed sample was 27 ± 2 on the same arbitrary scale as in the bond scans. In some cases we detected remarkably higher values associated with confirmed or possible delaminations. A teflon film placed in this area underneath the thinner copper film inhibits the structure from becoming fixed during the lamination. This results in a delamination. Also, one sample failed the so-called vacuum test, which is a standard method to detect delaminations. The latter delamination was also detectable by thermal waves. Table 1 below includes some examples of measured signals and the descriptions of the cases.

Table 1. The magnitude of photothermal signal between the weldings.

Magnitude (arbitrary units)	description of the sample
27 ± 2	normal good samples (limits show the minimum and maximum signals detected)
35	no cleaning prior to lamination
32	failed vacuum test
44	teflon film under the copper film
39	

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